This Week's Citation Classic™

Callen H B & Welton T A. Irreversibility and generalized noise.
Phys. Rev. 83:34-40, 1951.
[Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, PA]

The linear response of a system to externally applied forces is quantitatively related to the fluctuations of that system in thermodynamic equilibrium. [The *SCI*® indicates that this paper has been cited in over 370 publications since 1955.]

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July 18, 1984

"Ted Welton and I came to collaborate on the fluctuation-dissipation theorem from very different backgrounds, brought together by the happy accident of sharing an office as young faculty members at the University of Pennsylvania.

"I had been concerned with the theory of irreversibility since my dissertation, which had consisted of an application of Onsager's then-obscure 1931 paper[1] to thermomagnetic effects, and of a statistical mechanical derivation of Onsager's plausible (but not clearly rigorous) arguments. Welton's interest was primarily in quantum field theory, but Sam Schweber (then a graduate student) had asked for his help in understanding a Massachusetts Institute of Technology Radiation Lab report in which the Nyquist[2] argument for Johnson noise was applied to antennae. The Nyquist argument had the flavor of generality beyond the electrical case, and everyone's memory of the period now seems to reflect an implicit suspicion of that generality. Ted and I talked at length about such a plausible generalization; when I finally undertook a direct quantum perturbation analysis it was but a single evening's work to derive the fluctuation-dissipation theorem.

"The numerous references to the paper derive from its central role as the basis of linear response theory. In the hands of Ryogo Kubo,[3] the theorem was given an elegant and powerful formulation, and Kubo then applied it extensively to the calculation of linear responses. In the form of the 'spectral theorem,' it underlies the powerful and widely applied method of Green's functions in the analysis of macroscopic processes. The theorem also generalized the Onsager 'reciprocal relations' to arbitrary linear processes (other than simple relaxation processes). But I like to think that its impact also lay in the conceptual interpretation, in which we shifted the viewpoint from the effect of the signal generator on the macroscopic system to the inverse view—the effect of the complex system in destroying the coherence of the signal generator.

"A particularly interesting application of the theorem to the irreversible thermodynamics of black holes, by Candelas and Sciama,[4] extends the theorem to an unexpected and startling domain.

"As to awards associated with this work, in January 1984, I was awarded the Elliott Cresson Medal of the Franklin Institute for 'contributions to the statistical theory of irreversible processes and thermodynamic fluctuation theory, and especially for formulation and proof of the general Fluctuation-Dissipation Theory.' "

1. **Onsager L.** Reciprocal relations in irreversible processes. I. *Phys. Rev.* 37:405-26, 1931. (Cited 845 times since 1955.)
2. **Nyquist H.** Thermal agitation of electric charge in conductors. *Phys. Rev.* 32:110-13, 1928. (Cited 270 times since 1955.)
3. **Kubo R.** Statistical-mechanical theory of irreversible processes. I. General theory and simple applications to magnetic and conduction problems. *J. Phys. Soc. Jpn.* 12:570-86, 1957. (Cited 1,840 times since 1957.)
4. **Candelas P & Sciama D W.** The irreversible thermodynamics of black holes. *Gen. Relativ. Gravit.* 9:183-7, 1978. (Cited 1 time.)

